DYNAMICAL FEATURES OF THE METEORITE ICE FIELD, ANTARCTICA

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Abstract: Results of the glaciological work made in 1969 and 1973–1974 near the Yamato Mountains showed that the dynamical features of the southern Meteorite Ice Field (bare ice) were quite different from those of the ice sheet in the Shirase drainage, East Antarctica. In the ice field, ice flowed toward the Yamato Mountains with the small horizontal velocity less than 2 m/year; the vertical movement of ice indicated the emergence velocity of 5 cm/year on the average, and the mean ablation rate amounted to 5 cm/year in water equivalent. Discussions were also made whether or not the hypothetical idea of the concentration of meteorites within a limited area is possible, in terms of a mass budget study in the present drainage system. The result revealed that, if a number of meteorites had once fallen uniformly over the hinterland of the drainages of the Shirase Glacier and of the Meteorite Ice Field, more than 95% of the meteorites were drained off through the coast of the ice sheet, and only a few percent of them were conveyed to and exposed on the bare ice field around the Yamato Mountains.

1. Introduction

To elucidate the mechanism of accumulation of a large number of meteorites in a limited region, *i.e.* the Meteorite Ice Field (YANAI, 1978; MATSUMOTO, 1978), detailed information is much sought on the ice flow in the bare ice field surrounding the Yamato Mountains, East Antarctica. Surveys of a triangulation chain were carried out in December 1969 (NARUSE *et al.*, 1972) and in December 1973 to January 1974 (NARUSE, 1975) for the studies on the dynamics and the mass budget of the Mizuho Plateau ice sheet. The triangulation chain, which is composed of 164 stations, stretched for 250 km on 72°S between A001 (Motoi Nunatak) at the southeast end of the Yamato Mountains and S240 at 43°E in longitude. The surface elevation along the chain increased gradually from 2250 m near A001 to 2600 m near S240, so the chain was approximately parallel to a surface contour line. Obtained from the surveys were horizontal and vertical components of surface velocities at 140 points and also parameters of strains in 140 triangles of the chain. The results were published in another article (NARUSE, 1978) with some discussions on the general flow pattern and the local mass budget of the ice sheet in Mizuho Plateau.

The present paper gives firstly some characteristic features of the dynamic conditions of the Meteorite Ice Field, and discusses secondly on the propriety of the hypotheses which were given by SHIMA *et al.* (1974), YANAI (1978) and NAGATA (1978) on the mechanism of concentration of meteorites within the Meteorite Ice Field.

2. Glaciological Features of the Southern Meteorite Ice Field

Characteristics are quite different of the surface features and the ice flow in the Meteorite Ice Field from those in the inland ice sheet of Mizuho Plateau. Fig. 1 shows the distributions of the horizontal flow vector (m/year), the principal strain rate (1/year) and the emergence or submergence velocity (cm/year) of the ice or snow surface in the vicinity of the Yamato Mountains, namely the region from 36°10′E to 37°20′E in longitude. The 10-m interval contours are drawn from the results of the triangulation survey and observation of surface slopes of the ice sheet. The emergence or submergence velocity U of the ice at the surface was ob-

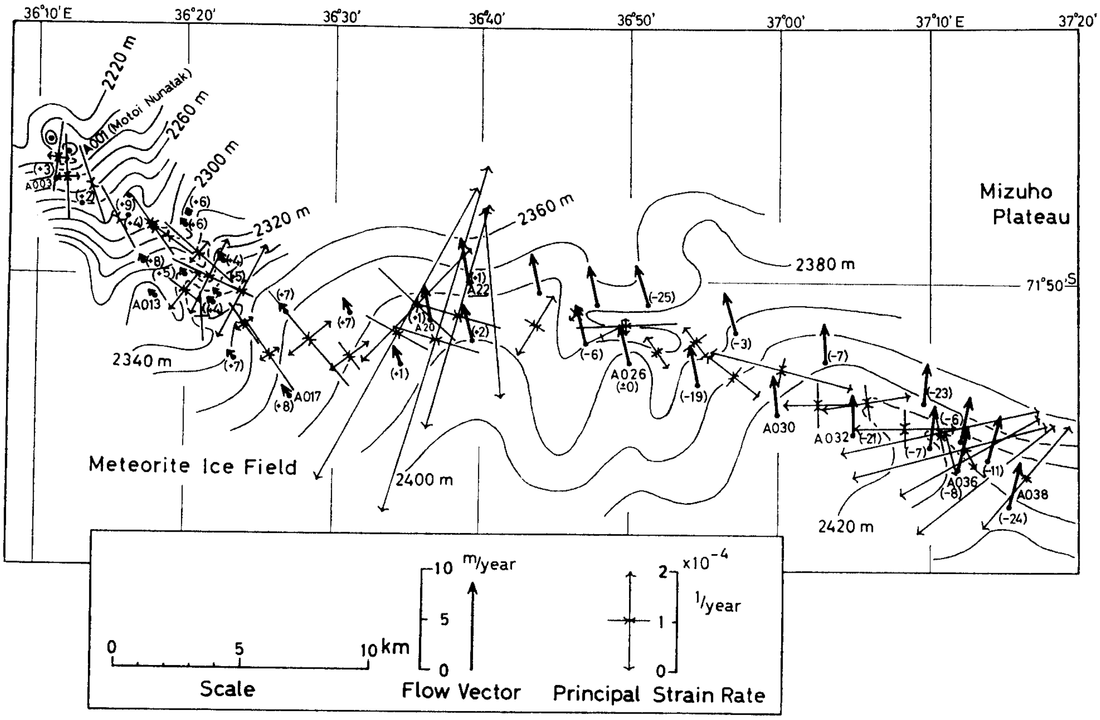


Fig. 1. Distribution of horizontal vectors of ice flow and principal strain rates in the southern Meteorite Ice Field and its east region.

Emergence velocity (positive value) or submergence velocity (negative value) are given in parentheses (cm/year). The number with A shows the station number. Surface contours of the ice sheet are drawn for every 10 m.

tained from

$$U = V_z + V_x \tan \alpha,$$

where V_z is the vertical velocity component of the top of a marker stake, V_x is the horizontal velocity and α is the surface slope (positive sign) along the flow direction. Values of U and V_z are now taken positive upward.

The following dynamical features are clearly noticed from Fig. 1:

1) Surface relief has remarkably irregular undulations over the region to the west of 37°20′E.

2) The flow velocity has very small values less than 2 m/year and the flow direction is northwestward in the vicinity of the Yamato Mountains, *i.e.* the region from A003 (36°10′E) to A020 (36°35′E). The small value is considered to be caused by the effect of many nunataks lying downstream. As a consequence, the mode of ice deformation was longitudinally compressive, as seen in the pattern of the principal strains.

3) The flow velocity increases gradually with the increase of distance from the nunataks. The value is 4.6 ± 0.4 m/year at A038, whereas the maximum velocity among all the triangulation stations is 21.3 ± 0.7 m/year at A069 (71°54′S, 39°10′E).

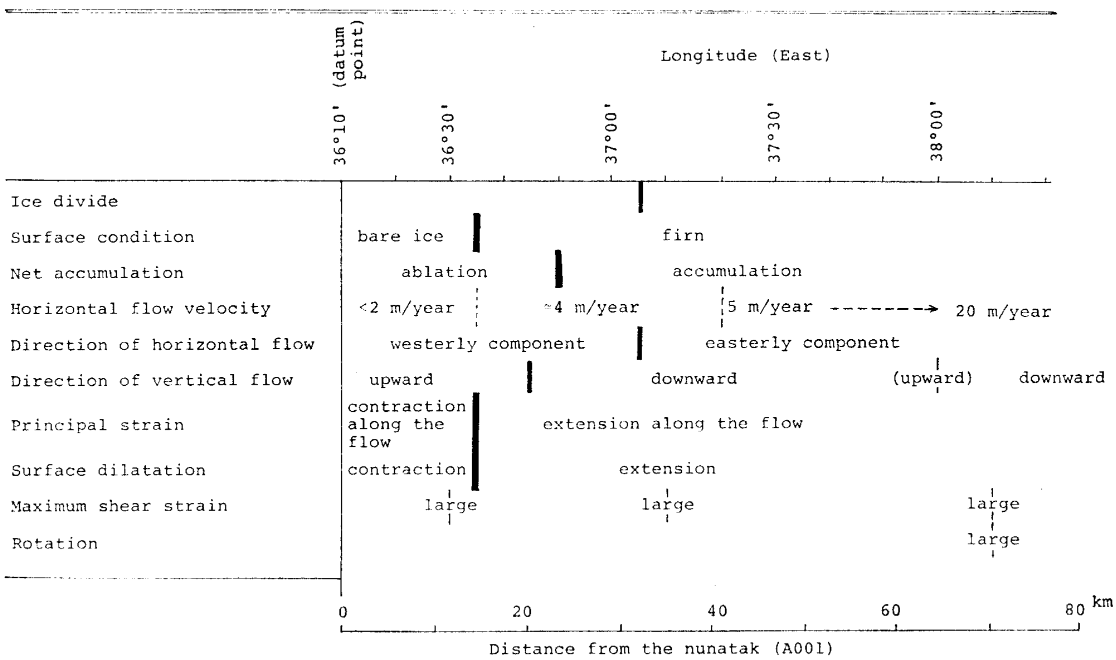
4) The flow direction shifts gradually from northwestward to northward in the region from 36°20′E to 37°E, and then the flow has an easterly component in the region to the east of A032 (37°05′E). Surface contours of the ice sheet show a ridge around the point A032. It can be considered, therefore, that an ice divide in this area exists near 37°E between the drainage of the Shirase Glacier and the drainage at its west side.

5) The direction and magnitude of the principal strains vary considerably in the distinct surface undulations as seen around the ridge at A030–A036. Large tensile strains along the direction from SSW to NNE noted near A020 can be understood to have resulted from the existence of large-scale crevasses which run along the direction from WNW to ESE. Tensile strains along the flow direction are generally predominant in the eastern region from 36°35′E in Mizuho Plateau (NARUSE, 1978; NARUSE and SHIMIZU, 1978).

6) The vertical movement of the surface ice indicates an upward mode in the bare ice field to the west of 36°45′E. The mean emergence velocity is 5 cm/year in the field.

Several glaciological characteristics including those mentioned above are summarized in Table 1. The annual net accumulation was negative, that is ablation due mainly to sublimation of ice, in the region to the west of 36°50′E. The mean ablation rate there was 5 cm/year in water equivalent, whereas the mean annual net accumulation in the region from 37°E to 43°E was 20 cm/year in snow depth, which corresponded to 9 cm/year in water.

Table 1. Glaciological features of the Meteorite Ice Field to the south of the Yamato Mountains.



It is found from Table 1 that clear boundaries of the dynamic conditions should exist at around 36°35′E–37°05′E. Namely, the features of the dynamic conditions of the Meteorite Ice Field are remarkably different from those of the ice sheet belonging to the drainage of the Shirase Glacier. No evidences were observed to support that the ice flow converged within the southern Meteorite Ice Field from the inland area of Mizuho Plateau. Flowlines are diverging rather than converging over the surveyed region in the vicinity of the Yamato Mountains (Fig. 1).

3. Possibility of the Concentration of Meteorites

Since the first discovery of Yamato meteorites in 1969, several ideas have been proposed on the reason and mechanism of the high concentration of meteorites in a limited bare ice field. YOSHIDA *et al.* (1971) suggested the contribution of the movement and structure of the ice sheet. SHIMA *et al.* (1973, 1974) were also in favor of the idea of concentration of meteorites due to the ice sheet flow. SHIRAISHI *et al.* (1976) interpreted the exposure of ice-buried meteorites on the basis of the observational results of the upward ice movement and the ablation of ice in the southern Meteorite Ice Field. NAGATA (1978) studied semi-quantitatively the mechanism of the transportation of meteorites by the ice movement and their accumulation on the bare ice surface. YANAI (1978) illustrated a hypothetical figure for a concentration mechanism of Yamato meteorites.

It is plausible to consider such a mechanism that a meteorite fallen once on the snow surface in the upstream region from the Yamato Mountains is buried by the overlying snow and is conveyed downstream with the ice flow having the downward component, and when the meteorite reaches occasionally the ice field near the Yamato Mountains, it is lifted up toward the ice sheet surface with the emergence flow of ice and is exposed there by the result of the sublimation of ice. However, one should carefully examine the hypothetical idea that a number of meteorites fallen over an extensive inland ice sheet have been concentrated within a limited bare ice field.

We now inspect the possibility of the meteorite concentration in terms of the mass budget study. Suppose the ice sheet is in a steady state; namely, the total amount of snow accumulation in a drainage equilibrates with the total amount of ablation. Average ablation rate was obtained as 5 cm/year in water equivalent over the ice field to the south of the Yamato Mountains. The total extent of the bare ice field around the Mountains was estimated at 4000 km^2 (YANAI, 1978). Assuming the uniform ablation rate over the ice field, the total amount of the loss of ice is 2×10^8 ton/year. Whereas, annual net accumulation was estimated in a range from 2 to 8 cm/year in water equivalent over the inland ice sheet with the surface elevation from 2500 m to 3500 m (YAMADA and WATANABE, 1978). The mean value of accumulation rate, *i.e.* 5 cm/year, is just the same value of the mean ablation rate in the bare ice field. As the ice sheet is in a steady state, the extent of an accumulation area turns out to be 4000 km^2, in which the total amount of snow accumulation should compensate the ice mass consumed by ablation of ice in the bare ice field. As for the drainage basin of the Shirase Glacier, the area was estimated at 2×10^5 km^2 (SHIMIZU *et al.*, 1978), the total amount of accumulation rate was $(13\pm8)\times10^9$ ton/year (YAMADA and WATANABE, 1978), and the discharge of ice through the Shirase Glacier was $(7.4\pm1.9)\times10^9$ ton/year (NAKAWO *et al.*, 1978). Then, the ratio of the total amount of ablation in the Meteorite Ice Field to the amount of the discharge of the Shirase Glacier counts 1/37. It follows that, if a number of meteorites had fallen with an uniform distribution over the inland ice sheet of the drainages of the Shirase Glacier and of the Meteorite Ice Field, more than 95% of the meteorites were drained off through the coast of the ice sheet, and only a few percent of them were exposed on the bare ice field around the Yamato Mountains. Under the present regime of the ice sheet dynamics, it seems improbable that the meteorites have concentrated within a much smaller area near the Yamato Mountains from the vast hinterland of Mizuho Plateau. It is possible that the drainage system and dynamical conditions were quite different from now in the past years. Detailed mechanism to elucidate the highly dense occurrences of meteorites remains unexplained until further studies are made on the dynamics of the present and past ice sheet as well as on the history of ice and meteorites. A clue may be obtained from drillings into ice and glaciological traverses along flowlines from the Meteorite Ice Field to the source of its drainage.

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